Exploring current sense amplifiers

STMicroelectronics Tech days

Application-dependent error sources

Chapter 9

- Input bias current
- Shunt resistance

User guide

This presentation provides a written explanation of the topic covered in the nineteenth chapter of the video: **“Application-dependent error sources #9”**, which is available on our YouTube channel at the following link:

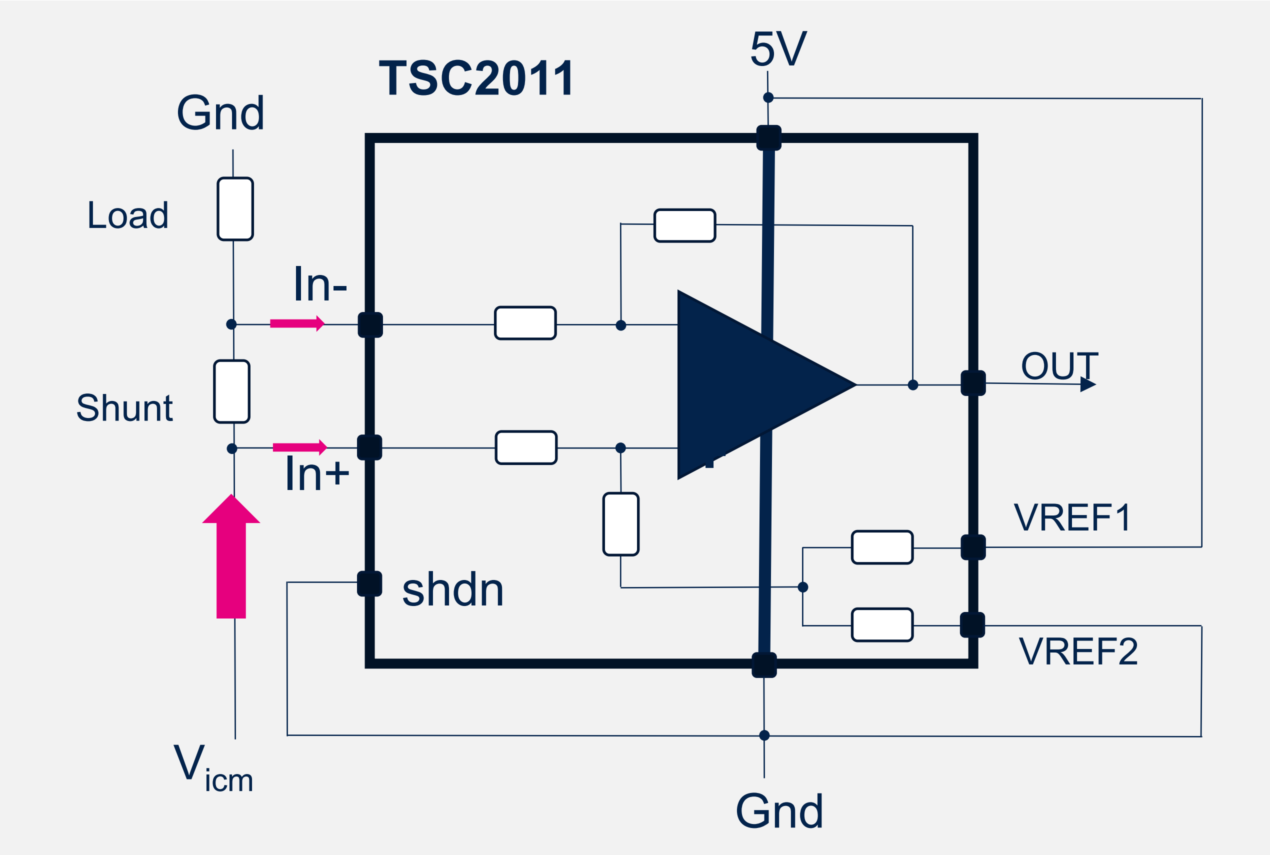
Video on YouTube

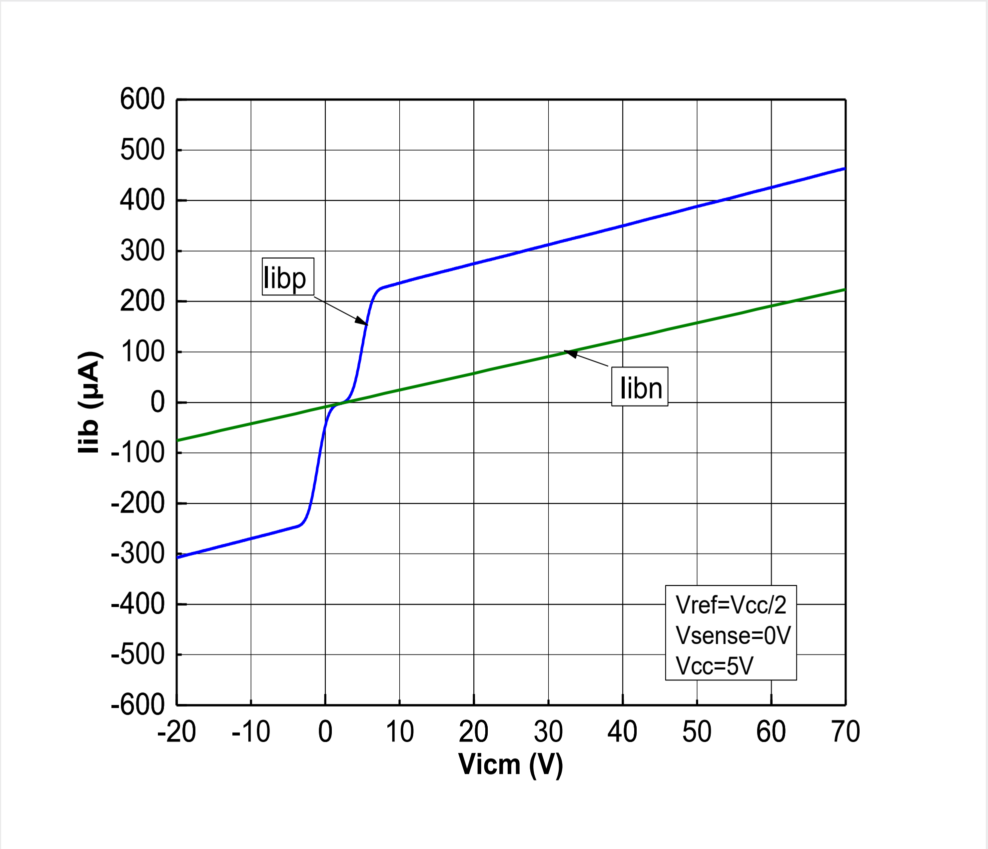
Recommendations

In this document you’ll find key concepts explained through informative tables, graphs, sequences of graphs, followed by a detailed explanation.

- When you see this icon: Explanation the topic is explained in detail on the following page(s)
- Each explanation page shows the page or page range where the topic is explained: (page # to #)
- If you see this icon: Continue the explanation continues on the next page(s)

Input bias current





TSC2010 series

I_{ib+}	Input bias current	V_{icm} = 12 V		350		µA
		$T_{min} < T < T_{max}$, V_{icm} = -20 to 70 V	-400		600	
I_{ib-}	Input bias current	V_{icm} = 12 V		100		
		$T_{min} < T < T_{max}$, V_{icm}= - 20 to 70 V	-150		350	

Explanation of page 4

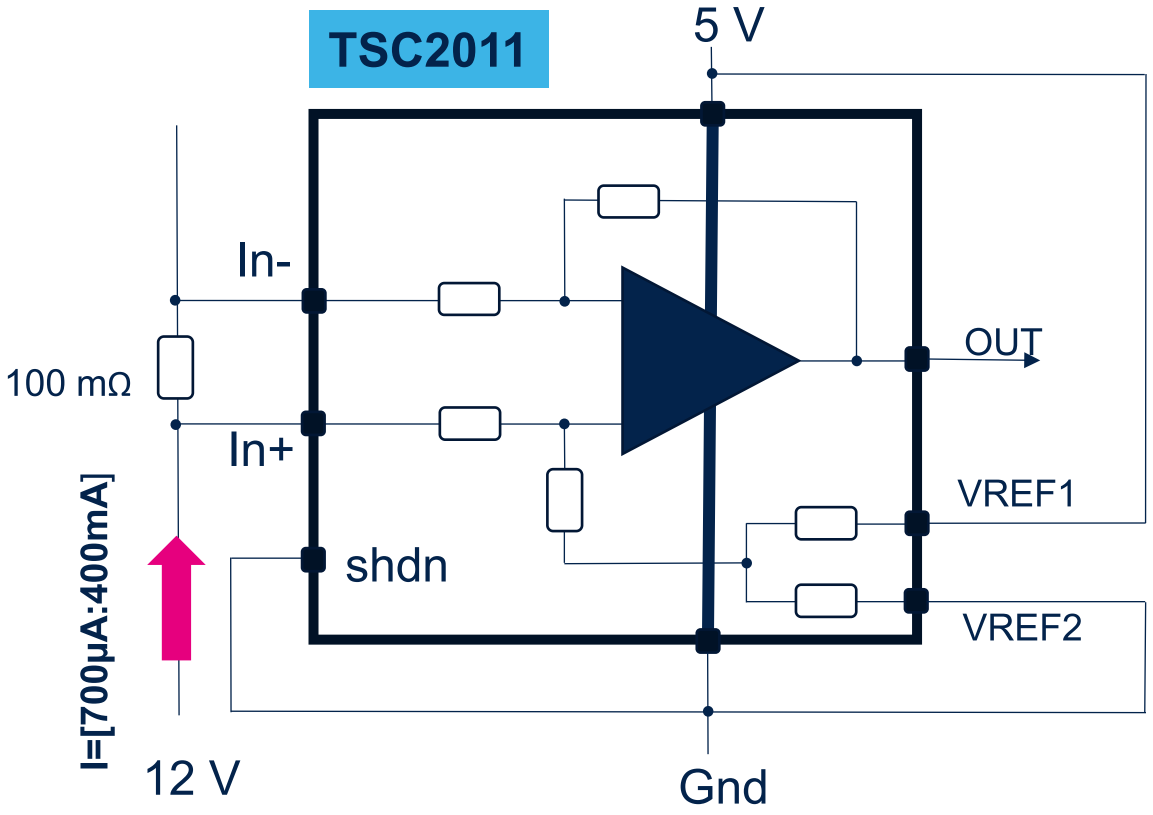
The **input bias current** is the current flowing into the **positive and negative inputs** of the current sense amplifier. In current sense amplifiers, this current is usually higher than in standard operational amplifiers, typically ranging from a few μA to several hundred μA.

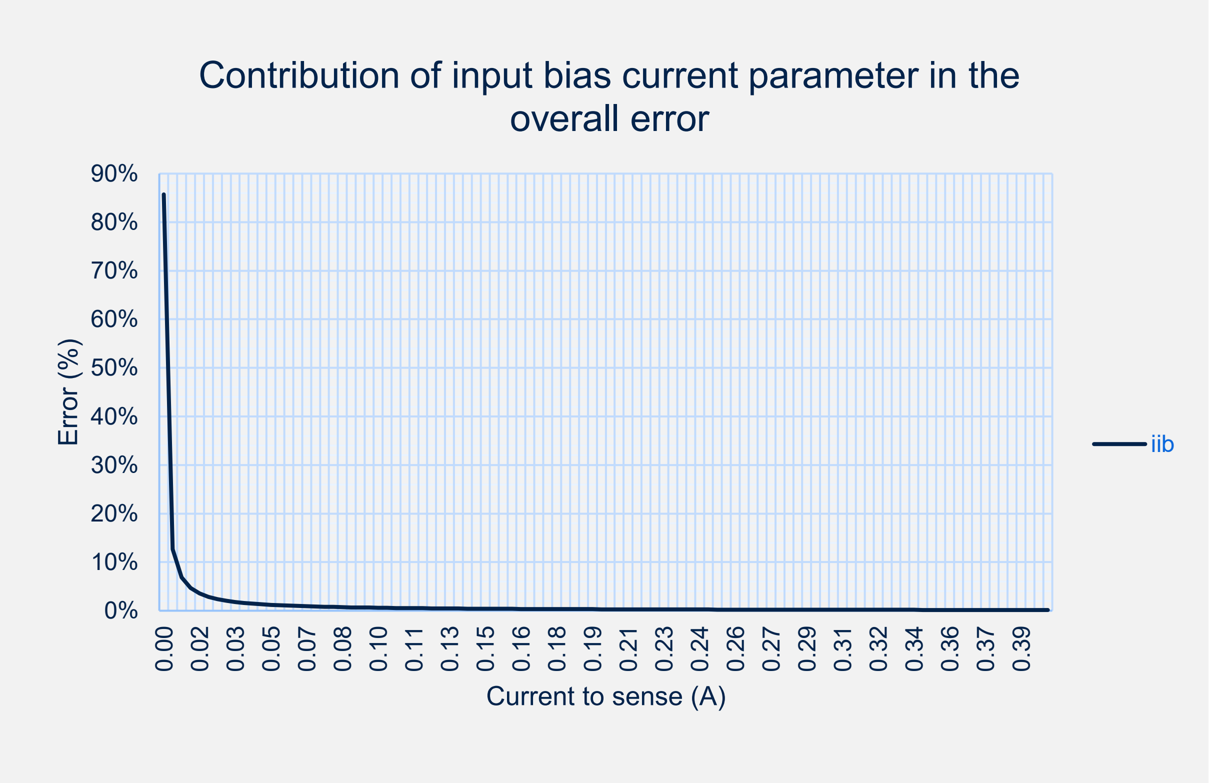
This is mainly due to the architecture of the current sense amplifier, which is designed to operate with an **input common-mode voltage** that can be far beyond the V_{CC} supply range.

For example, in a classic differential current-sense architecture such as the TSC2010, when the common-mode voltage is higher than V_{CC}, current flows through the internal resistors. In addition, to withstand a common-mode voltage much higher than its own supply voltage, the input stage also requires current, which is drawn from the **common-mode supply bus**.

Example

$$Iib\ impact(\%) = \frac{Iib}{I_{sense}} * 100$$





Example

Explanation of page 6

A first key point is that the current flowing through the shunt resistor should be **much higher than the input bias current**. Otherwise, the error caused by the input bias current must be included in the analysis.

This error can be expressed by the equation shown, which gives the ratio of the **input bias current** to the **measured current**.

$$Iib\ impact(\%) = \frac{Iib}{I_{sense}} * 100$$

The graph illustrates the expected error over the current range when only the input bias current is considered. With the [TSC2011](TSC2011) at $V_{icm} = 12\ \mathrm{V}$, a typical error below 5% can be expected only when the measured current is greater than $7\ \mathrm{mA}$.

Shunt resistance error

Shunt tolerance (%)

Tempco (ppm/°C)

EMF (µV/°C)

STANDARD ELECTRICAL SPECIFICATIONS						
GLOBAL MODEL	SIZE	POWER RATING $P_{70\,°C}$ W	TOLERANCE ± %	RESISTANCE VALUE RANGE Ω	RESISTANCE VALUES CURRENTLY AVAILABLE (1) Ω	WEIGHT (typical) g
WSBS5216	5216	12	5, 10	50µ to 250µ	100µ	19.2

TECHNICAL SPECIFICATIONS		
PARAMETER	UNIT	RESISTOR CHARACTERISTICS
Temperature coefficient	ppm/°C	± 150
Temperature coefficient (element material)	ppm/°C	± 20
Operating temperature range	°C	-65 to +170
Thermal EMF	µV/°C	< 1 for 100 µΩ
Inductance	nH	< 5
Maximum continuous current rating	A	$(P/R)^{1/2}$

Specification from Vishay shunt resistance

$$Shunt\ error = \varepsilon shunt + \varepsilon shunt_{tempco} * \Delta T + EMF * \Delta Te2e$$

$(\Delta Te2e)$ temperature variations across the resistor

Shunt resistance error

Explanation of page 8

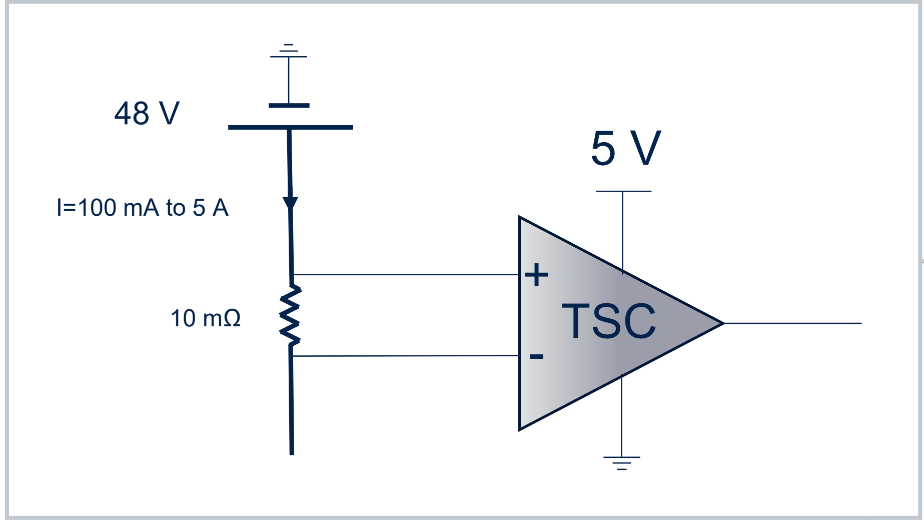
Although the shunt resistor isn't integrated into the current sense amplifier, it's an essential part of the current measurement and must be considered in the overall accuracy analysis.

Several shunt-related parameters contribute to measurement inaccuracy. The first is **shunt tolerance**. This error term depends on the application and isn't related to the current sense amplifier itself, but it's a major contributor to the total system error. Its effect is similar to the amplifier **gain error**, since it acts as a ratio on the measured current. As defined in the shunt datasheet, a 5% tolerance on the shunt resistance directly results in a 5% current measurement error.

The shunt resistance value also varies with temperature, so its **temperature coefficient** must be taken into account. In the example shown, a temperature increase of $100°\mathrm{C}$ from ambient adds 1.5% error to the current measurement.

A last parameter to consider is the **thermal EMF**. This is a very small voltage, typically in the μV range, generated by an end-to-end temperature difference ΔT_{e2e} across the resistor. Its effect is closer to an **offset error**, such as $\mathrm{d}V_{io}/\mathrm{d}t$.

Example



The shunt adds 6.5% error @125 °C for a current of 100 mA to measure.

Error estimation due to shunt resistance

$Shunt\ error$=0.5%+100ppm∗100°C+ 5µV∗10°C

Impact on current measurement 100mA

$Theoretical\ Vsense = 100\ mA * 10\ m\Omega$ = 1mV

$V_{sense}\ due\ to\ shunt\ error = 1.065\ mV$

Particularity

- Iload=100 mA to 5 A
- R_{shunt}=10 mΩ
- Tolerance=0.5%
- Tempco = 100ppm/°C
- Temperature range=125°C
- EMF=5µV/°C
- A temperature difference between both connections of the shunt is 10°C

Explanation of page 10

This example shows how shunt resistor inaccuracies can significantly affect current measurement.

The application measures current from **100 mA to 5 A** using a **10 mΩ shunt** at **125°C**. Although a high-performance shunt is selected, the temperature gradient across its terminals is high.

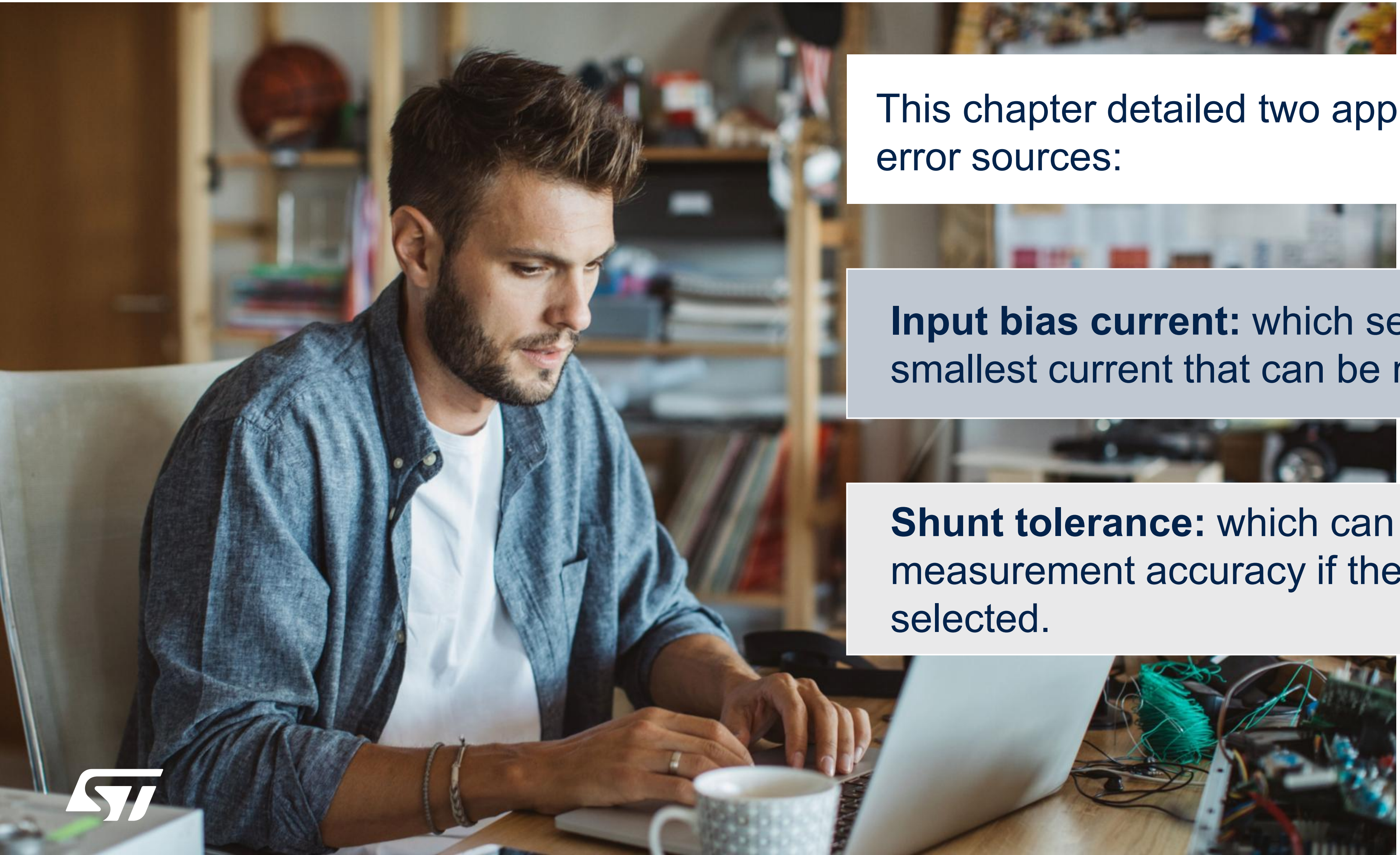
The shunt has an initial tolerance error of **0.5%**. At **125°C**, the temperature coefficient must also be considered, increasing the shunt-related error to **1.5%**.

In addition, the temperature isn't uniform around the shunt, and a **10°C difference** appears between its two terminals. This creates a **thermal EMF** that adds a **50 µV offset** at **125°C**. For the minimum measured current, **100 mA**, this corresponds to an additional **5% error**.

Ideally, the sense voltage is **1 mV** for **100 mA** through a **10 mΩ shunt**. But when all shunt error sources and temperature effects are included, V_{sense} rises to **1.065 mV**, leading to a total shunt-related inaccuracy of **6.5%** for the **100 mA** measurement.

This example shows that choosing a current sensor with very low impact is important, but selecting the right shunt resistor with the same level of care is equally essential.

Summary of percentage-based error sources



This chapter detailed two application-dependent error sources:

Input bias current: which sets a limit on the smallest current that can be measured accurately.

Shunt tolerance: which can significantly affect measurement accuracy if the shunt isn't carefully selected.

Summary of percentage-based error sources

Explanation of page 12

This chapter has presented **two error sources** that are more application-dependent

1. The input bias current, which sets a limit on the smallest current that can be accurately measured.
2. The shunt tolerance, which can significantly impact the measurement accuracy if the shunt isn't selected carefully.

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